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Investigation on The effect of Airgap Distance for Ignition Coils using Finite Element Methods

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Abstract – This study is related to the ignition coil which produces spark energy to ignite fuel mixture in cylinder of internal combustion motor. There are some problems that is commonly seen in automotive ignition coil. These problems lead to break down the spark plug by producing of low energy or high energy output. The mentioned output energy has 3 conditions which are low energy output, high energy output and optimal energy output. High voltage output leads to dry to airgap of spark plug. On the other hand, low voltage output leads to wet to airgap of spark plug. The purpose of this study is investigation on the ignition coil to be able to produce the best output which is optimal energy. To achive optimal energy output, an ignition coil model was designed in Ansys Maxwell environment. An ignition coil contains basically primary winding, secondary winding, core and resin for insulating. Optimal energy output is targeted by changing the airgap distance on the core of ignition coil. An experiment table was created to provide the optimization for output energy of ignition coil. This experiment table consists of different airgap distances of core on ignition coil. All combinations in the experiment table was simulated on the model of ignition coil by using finite element analysis. Finally, all simulation results from experiment table were evaluated aspect of relationship between airgap distance for core of ignition coil and output energy of ignition coil.

Keywords ***-***
Ignition Systems, Finite Element Method, Automotive Ignition Coils.

1. Introduction

Internal combustion motor having ignition system carry typically 20-30 kV and 30-100mA on the airgap of spark plug. This systems are characterized efficieny less than 1%. Most of

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produced energy is consumed on spark plug cable, spark plug and resistors of transformer. This operation mode is not enough for most of motor. And so, high voltage decharge energy requires to ignite effectively mixture of air and fuel. The growing of ignition power and energy requirement requests more effective ignition systems. [1]

The electronic ignition coils tranfer high ignition energy and high voltage in comparison with conventional ignition coil. The ignition systems can be characterized to understand spark power and spark energy at different operating conditions in terms of electrical parameters. The Energy value can be evaluated as a function of time at decharge conditions. Typically, energy level is about 50 mJ. [2]

Input energy, timing of spark delay, electrical resistance, the airgap distance on piston and electrical output are important key parameters for ignition systems. [3]

The load of various nominal energy (100-1000mj) and inductance (0.024-1.454 mH) are used with different trigger method. Decharge efficiency and its time depend on inductance of load. Minimum ignition energy is an important parameter of risk evaluation. To calcute correctly minimum ignition energy is important to prevent the explosion [4]

$$E = 0.5 * C * U^2 \qquad (1)$$

Wherein E (Joule)is stored energy, C (Farad) is total decharge capacity and U (Voltage) is the charging voltage of capacitor.[4]

2. Automotive Ignition Systems

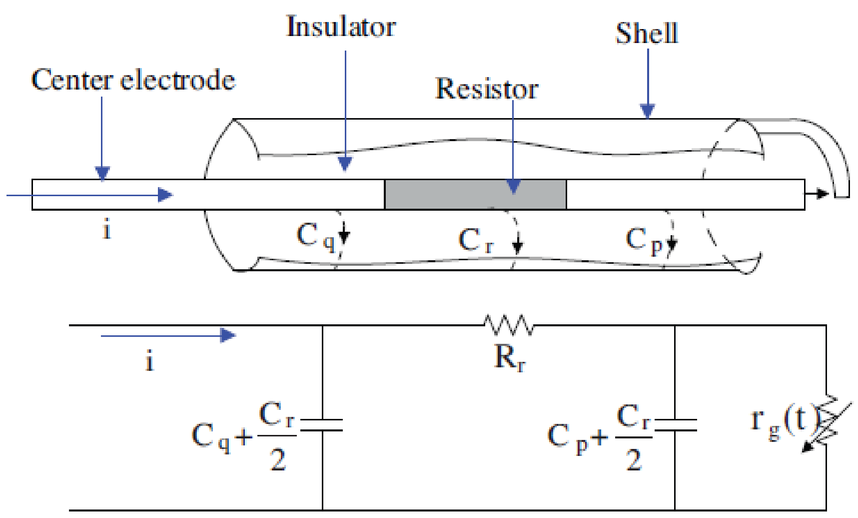

Figure 1: Spark Plug Electrical Circuit Model

The electrical circuit model of spark plug is shown in Figure 1. Where resistor Rr is series resistor that is defined by manufacturer. Resistor rg is airgap resistance fors park plug. Capasitors Cp,Cq and Cr are parasitic resistors. The result of finite element method analysis for Figure 1 model show that Cq = 5.40 pF, Cp=4.99 pF ve Cr = 5.88 pF. Resistor Rr is 4.98 kohm. [5]

Because ignition energy effects directly emission performance of vehicle, fuel saving and power perfomance, it is one of important parameter. Today, the 3 important factor of developing vehicle are environment friendly, fuel saving and safety. The electronic ignition systems have been one of the research issue to increase to efficieny of ignition energy. Ignition energy is an indispensable element of ignition system. The problem of ignition energy leads to decrease power and torque values of the engine. The ignition coils are application units of a vehicle's ignition system. These ignition coils provide ignition energy to ignite mixture of air-fuel in engine. Basically, primary winding and secondary winding of ignition coil charge and decharge the energy repeatedly. The working principle of ignition coil is shown in Figure 2. [6]

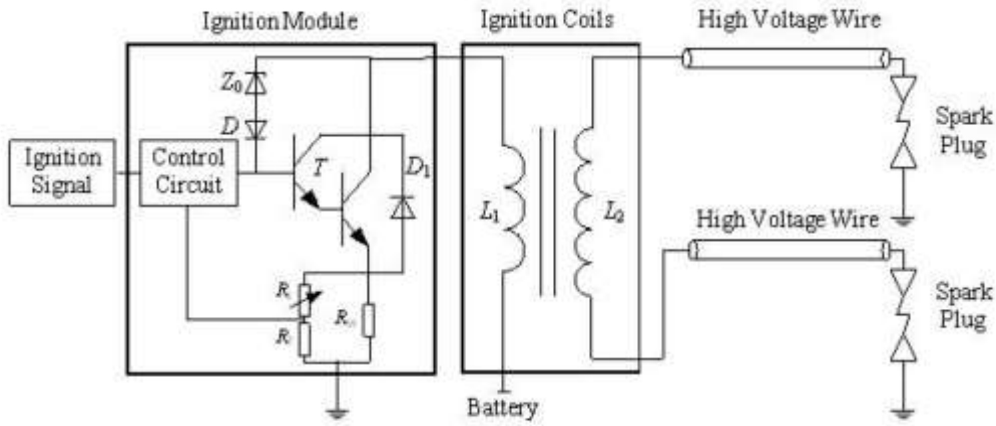

Figure 2: The Working Principle of Ignition Coil.[6]

The ignition system can be investigated 3 phases. Firstly, producing an ignition signal from a electronic circuit drives a transistor. Secondly, when cutting off the transistor driving, a high voltage induced on secondary winding. Finally, this high voltage is transmitted to spark plugs, then fuel is ignited. [7]

Table 1: The Working Characteristic of Typical Ignition Coil[8]

Output Energy	**Power Efficiency**	**Operating Temperature**	**Max. Operating Voltage**
70 mJ	> % 85	125 oC 1200	
@	@ 3000	Saat	
7.5A	RPM	@3000 RPM	35 Kv, 50 saat

The copper wires of secondary and primary winding has an insulating both core and itself.[9]

3. The Electrical Circuit Model of the Ignition Coil

Basically, the ignition coil works such as the transformers in terms of working logic. So an ignition coil can be modeled electrically. The electrical model consists of primary winding and secondary winding. The ignition coils as high voltage transformer converts low voltage level to high voltage level according to turns ratio between secondary and primary windings. The output high voltage of the ignition coils is connected to the spark plugs. And so, the spark plugs provides ignition energy to ignite the fuel. Figure 3 shows that electrical connection between an ignition coil and a spark plug.

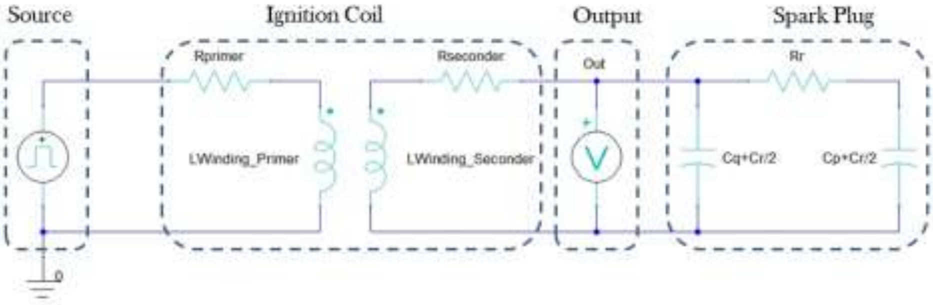

Figure 3: The Electrical Circuit Schematic Between Ignition Coil and Spark Plug.

The components on circuit in Figure 3 have some values and units which are shown in Table 2.

Tablo 2: The Characteristic of Electrical Parameter

Parameter	Value	Unit
Cp	5.00	pF
Cq	5.40	pF
Cr	5.88	pF
Rr	5	kohm
Rseconder	5	kohm
Rprimer	0.2	ohm
Secondary Turn Number	12000	turns
Primary Turn Number	150	turns

4. The Finite Element Model of Ignition Coil

A model of ignition coil was designed at Ansys Maxwell. The finite element solver for this model is aimed to use. An ignition coil contains basically primary winding, secondary winding, core, primary carcass layer and secondary carcass layer. Solving a 2D model of ignition coil is shown in Figure 4.

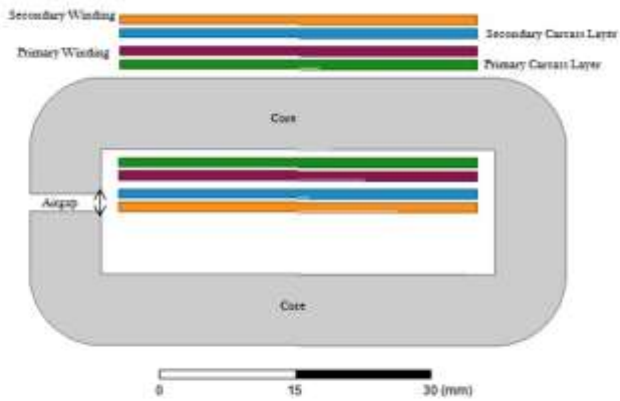

Figure 4: The 2D Model of Ignition Coil

As shown in Figure 4, the primary carcass layer was insert on core, then the primary winding was wonded on primary carcass layer, then the secondary carcass layer was insert on primary winding, then the secondary winding was wounded on secondary carcass layer. 3D model of this igniton coil shown in Figure 5.

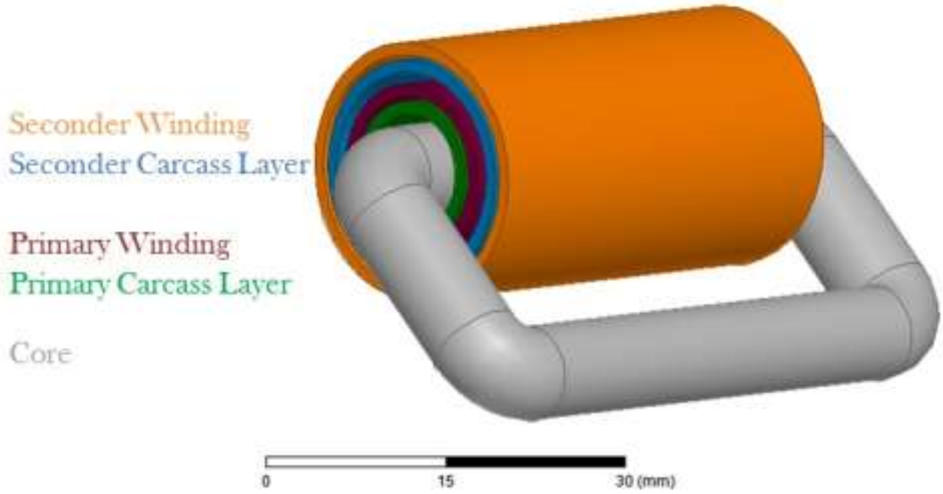

Figure 5: The 3D Model of Ignition Coil

The material characteristics for igniton coil is shown in Table3.The finite element mesh model for ignition coil in Ansys Maxwell environment is shown in Figure 6.

Table 3: Material Properties

Parameter	Materials
Secondary Winding	Copper
Secondary Carcass Layer	Polyamide
Primary Winding	Copper
Primary Carcass Layer	Polyamide
Core	Steel1008

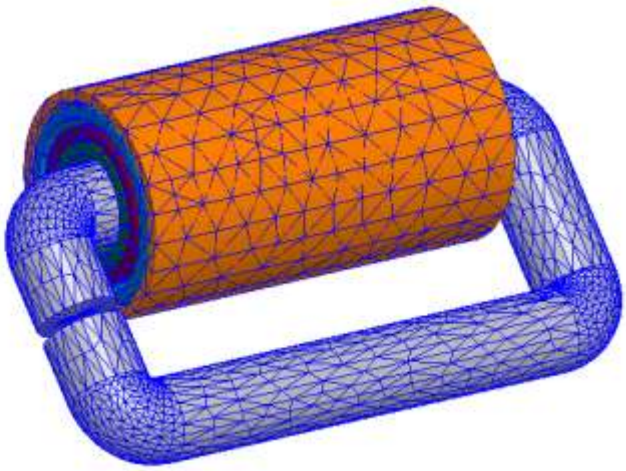

Figure 6: The Mesh Model for Ignition Coil

5. Experiments

The experiment series are aimed to create for observing the effect of the airgap distance on the core of the modelling ignition coil in Ansys Maxwell. These experiment series was configured for investigating on changing induced voltage and transmitted energy on seconder. These experiment series are shown in Table 4.

Table 4: Experiment Series for Airgap Distance

Experiment No	Distance	Unit
1	0.1	mm
2	0.5	mm
3	1	mm
4	1.5	mm

6. Results

In this section, the results from experiments in Table 4 were given. The induced voltage and current on seconder winding were investigated by changing airgap distance as shown in Table 4. The induced voltage and the current on seconder winding are respectively shown in Figure 7 and Figure 8.

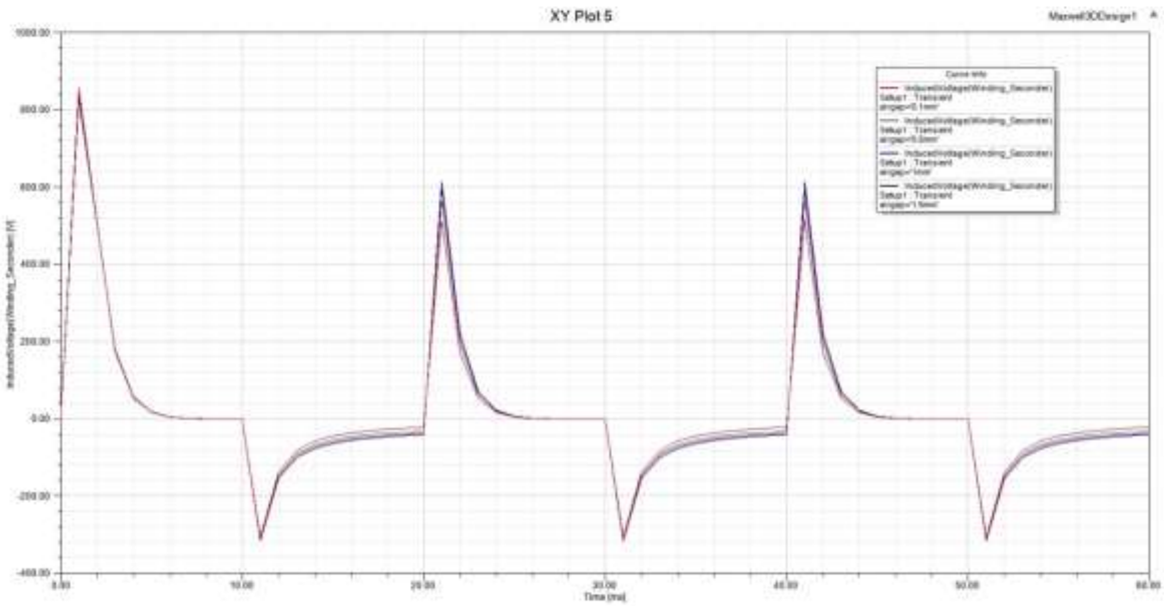

Figure 7: The Induced Voltage of Seconder Winding

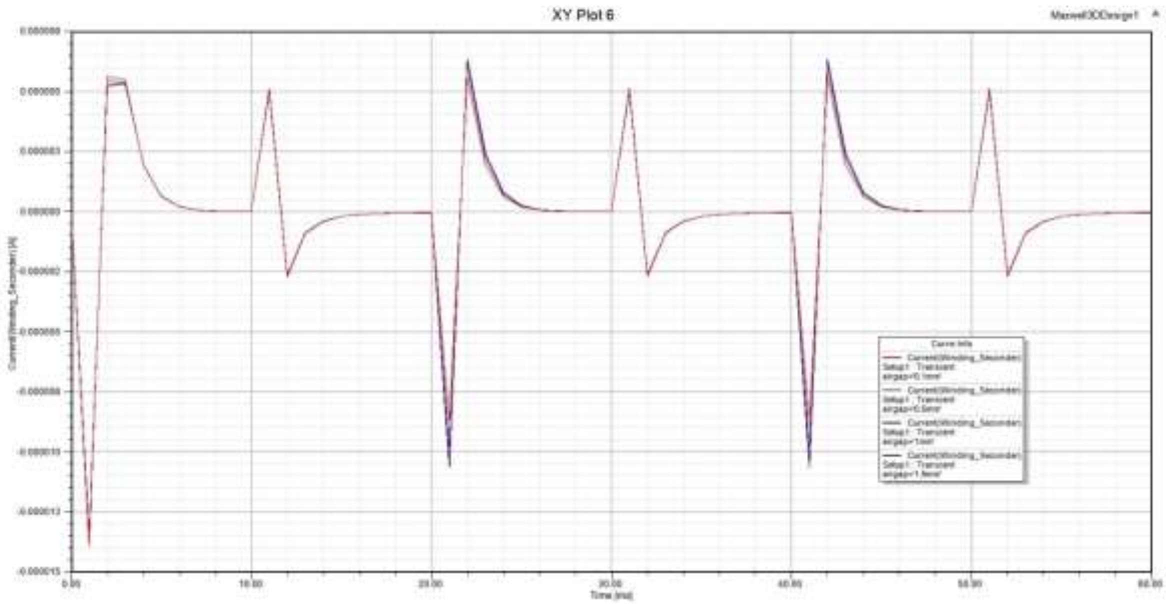

Figure 8: The Current of Seconder Winding

The Induced voltage shown in Figure 7-8 was investigated in terms of 3 period. The transmitted energy on seconder winding is shown in Table 5.

Table 5: The Effect of The Output Energy of Airgap Distance

Experiment No	AirgapDistance	Output Energy
1	0.1 mm	54.9 mj
2	0.5 mm	61.1 mj
3	1.0 mm	65.2 mj
4	1.5 mm	67.9 mj

The experiment results shown in Table 5 demonstrates to be able to produce different output energy as long as air gap distance on core can be adjusted. These results prevents failing of the spark plugs as a result of transmitted energy. Also, it can be contributed to fuel saving by using optimal energy in case of adjusting airgap distance.

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